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HIGH-TEMPERATURE MINIATURIZED TURBINE ENGINE LUBRICATION SYSTEM SIMULATOR

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A high-temperature miniaturized turbine engine lubrication system simulator was designed and fabricated for the purpose of evaluating limited quantities, 1 quart or less, of candidate Integrated High Performance Turbine Engine Technology candidate lubricants. The computer-controlled simulator can determine a lubricant's functional and tribological properties under a wide variety of operating conditions. Metal test coupons can be added to the system to evaluate a lubricant's corrosive properties. Operating parameters are 10,000 rpm, 100 Ksi Hertz stress bulk oil temperatures to 750°F, bearing temperatures to 850°F, and hot spots to 950°F. The simulator also has the capability for inert atmosphere and once through lubrication operation. Validation of the simulator was accomplished with 48-hour test runs using high temperature polyester and polyphenylether lubricants.

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HIGH-TEMPERATURE MINIATURIZED TURBINE ENGINE LUBRICATION SYSTEM SIMULATOR

A. INTRODUCTION/OBJECTIVE

Liquid lubricants used in aircraft turbine engines must perform not only the standard lubricating functions of preventing excessive wear and friction in gears and bearings, but they must also act as a coolant for many vital components. In order to perform this function satisfactorily, the lubricant must be compatible with the various metals, elastomers, and sealants with which it may come in contact during storage and handling as well as engine operation, and it must have high-temperature thermal and oxidative stability and resist deposition. These requirements are defined and controlled by several different specification tests, many of which require large volumes of fluid.

Advanced technology engines are being developed which will demonstrate a significant increase in efficiency and thrust-to-weight ratio. These developments will cause the engine to operate at higher temperatures and impose higher loads on the bearings resulting in a requirement for lubricants that can operate in the range of 500°-700°F. The current Air Force engine simulator for lubricant testing is limited to 400°F and requires a relatively large amount of lubricant (5 gallons). Thus, a new evaluation technique was needed that would be capable of determining a lubricant's functional and tribological properties under anticipated operating conditions of advanced turbine engines.

The objective of this project was to design and fabricate a miniaturized, generic, turbine-engine simulator to facilitate early evaluation of experimental, high-temperature liquid lubricants of limited quantity for potential application in advanced engines. The major design goals were as follows:

- Typical small, rolling-contact bearings at approximately 10,000 rpm with 100,000 psi Hertz stress
- Material compatibility with fluids or their byproducts which may be corrosive at high temperatures, e.g., polyphenyl ethers and perfluoroethers
- Capacity of experimental fluid: less than 1 quart
- Bulk oil temperatures to 750°F (400°C)
- Bearing temperatures to 850°F (455°C)
- Hot spots to 950°F (510°C)
- Measurement of all operating parameters of interest

- Continuous monitoring of torque

In addition, the system was to have the following capabilities:

- Placement of metal specimens in the oil to evaluate corrosive or catalytic effects
- Inerting
- Evaluating variables such as air input, oil filter porosity, and condensate return

Above all, safety of operation was to be considered along with compliance with all installation and operational regulations in place at Wright-Patterson Air Force Base (WPAFB), the final installation.

Of these requirements, dealing with the potential problems of candidate fluids, such as perfluoroethers, were the predominant concern because the degradation products of these compounds, such as carbonyl fluoride (COF2), can be highly corrosive to the metals that are commonly used in lubrication systems.

The product of this project was a unique, high-temperature, Miniaturized Turbine-Engine Lubrication System Simulator (MTELSS) which met these goals. This Simulator has been delivered and installed at WPAFB. The project was divided into five major tasks. Task 1 was a literature search to identify the best materials for corrosion resistance. Tasks 2 and 3 were the design and fabrication of the system, respectively. Task 4 was comprised of four tests on two different fluids; two of these were conducted at SwRI while the other two at WPAFB after installation there, which was Task 5.

B. LITERATURE SEARCH - TASK 1

The purpose of Task 1 was to review the available literature to aid in the selection of suitable materials for the MTELSS. Material requirements included a temperature capability up to hot-spot temperatures of 950°F (510°C) and compatibility with candidate fluids, primarily polyphenyl ether (OS-124) and perfluoroalkylpolyether (Krytox 143) heated to bulk temperatures up to 750°F (400°C). The reference sources used are given below:

- Lockheed Information System (DIALOG), containing 81 data bases
- System Development Corporation (ORBIT), containing 45 data bases
- Lubricants/lubrication research data bases for Chemical Abstracts Condensates, Engineering Index Monthly, SAE Abstracts, and the National Technical Information Service
- Nondestructive Testing Information Analysis Center (NTIAC)
- AFWAL/POSL research on materials at high temperature with various lubricants
- Monsanto Chemical Company
- E.I. duPont deNemours and Company
- Zenith Pump Company
- Superior Tube Company
- Inco Alloys International
- Int-Ex Gear and Spline Company
- SwRI Machine Shop
- Arthur Valve and Fitting Company
- Associated Spring Company
- Whitey Valve Company
- Swagelock Fitting Company
- Industrial Techtronics, Inc.

From the information gathered, the following materials were used for the various parts and components:

Material	Area	Machinability*	Weldability
Inconel	Test section housing, end caps, thermocouples fittings, tubing, bearing pre-load spring, oil sump, oil filter, valves, most oil wetted items	30%	Good
Stellite	Valve seats, oil pump gears, oil pump wear plate, bearings	Not req'd	Not req'd
Hastelloy	External oil pump housing, oil filter	40%	Not req'd
17-4 HP stainless steel	Test bearing ball separator	0%	Not req'd
* Additional machining required compared to 316SS			

Some of the rationale on these decisions are provided in the notes below:

Inconel 600 was used for almost all of the lubricant-wetted parts and fasteners of the MTELSS. This material is a nickel-chromium alloy with good oxidation resistance at high temperatures and resistance to chloride-ion stress corrosion cracking, corrosion by high-purity water, and caustic c rrosion.

Associated Spring Company recommended Inconel alloy 718 or alloy X-750 for the material of the test bearing preload spring. These alloys combine corrosion resistance and high strength with outstanding weldability and excellent creep-rupture strength at temperatures to 1300°F (700°C). Inconel X-750 has excellent relaxation resistance which makes it useful for high-temperature springs and bolts.

Stellite alloys are a cobalt-based alloy with high resistance to erosion as well as corrosion. They are characterized by high hardness at temperatures of 1470°F (800°C) and above. They find extensive use in high-temperature, corrosive applications requiring superior wear resistance. Consequently, they are an excellent candidate for bearings and gears which come in contact with corrosive fluids at high temperatures.

C. MTELSS SYSTEM DESIGN AND FABRICATION - TASKS 2 & 3

Figure 1 is a photograph of the entire MTELSS System. In the foreground is the Control Console on the left and the Computer System on the right; in the background is the MTELSS Test Stand. These three systems are described separately in the following discussion.

1. MTELSS Test Stand

a. Conceptual Design

Figure 2 illustrates the general concept of the MTELSS test section. It houses two, angular-contact, ball test bearings which are preloaded to obtain approximately 100,000 Hertz stress. These test bearings are mounted on a horizontal shaft that is driven by a variable-speed motor up to 10,000 rpm. The test section can be operated at bearing temperatures up to 850°F (455°C) through the use of two, separately controlled-band heaters mounted on the outside of the housing. The sump temperatures of the lubricant can be controlled to 750°F (400°C). A hot-spot with a controlled temperature capability of 950°F (510°C) is incorporated into the rear end plate; a heat shield has been placed between the hot-spot and the rear test bearing to reduce the effect of the hot-spot on the temperature of the bearing. Each bearing is lubricated by two jets of fluid. The test section is designed for only one specific sized bearing, but other sizes could be used (within the confines of the housing) by fabricating a new drive shaft, different spacers, and bearing preload device, none of which would be very expensive.

b. Test Stand

Figure 3 shows the assembly of the MTELSS system on the Test Stand. The Test Stand itself is composed of two independent frames bolted together; it was designed this way for ease of maintenance. The lubricant flow system is located on the forward frame, and the MTELSS drive system is located on top of the rear frame. Electrical and electronic packages pertinent to the components on each of these stands are also located on the frame.

c. Test Head

Figure 4 shows the major components of the MTELSS Test Head consisting of the housing, the end caps, the outer bearing holders, and the shaft with the test bearings. The end plates are secured to flanges on the main housing with quick-disconnect, V-band coupling clamps to aid in disassembly. Figure 5 is an assembly drawing of the Test Head; the instrumentation is shown in this figure. The Test Head is fabricated entirely from Inconel.

d. Test Bearings

The design of the MTELSS Test Section were based on the No. 2 bearing from the Allison T63 engine as the test bearings for test temperatures up to 650°F (344°C). This

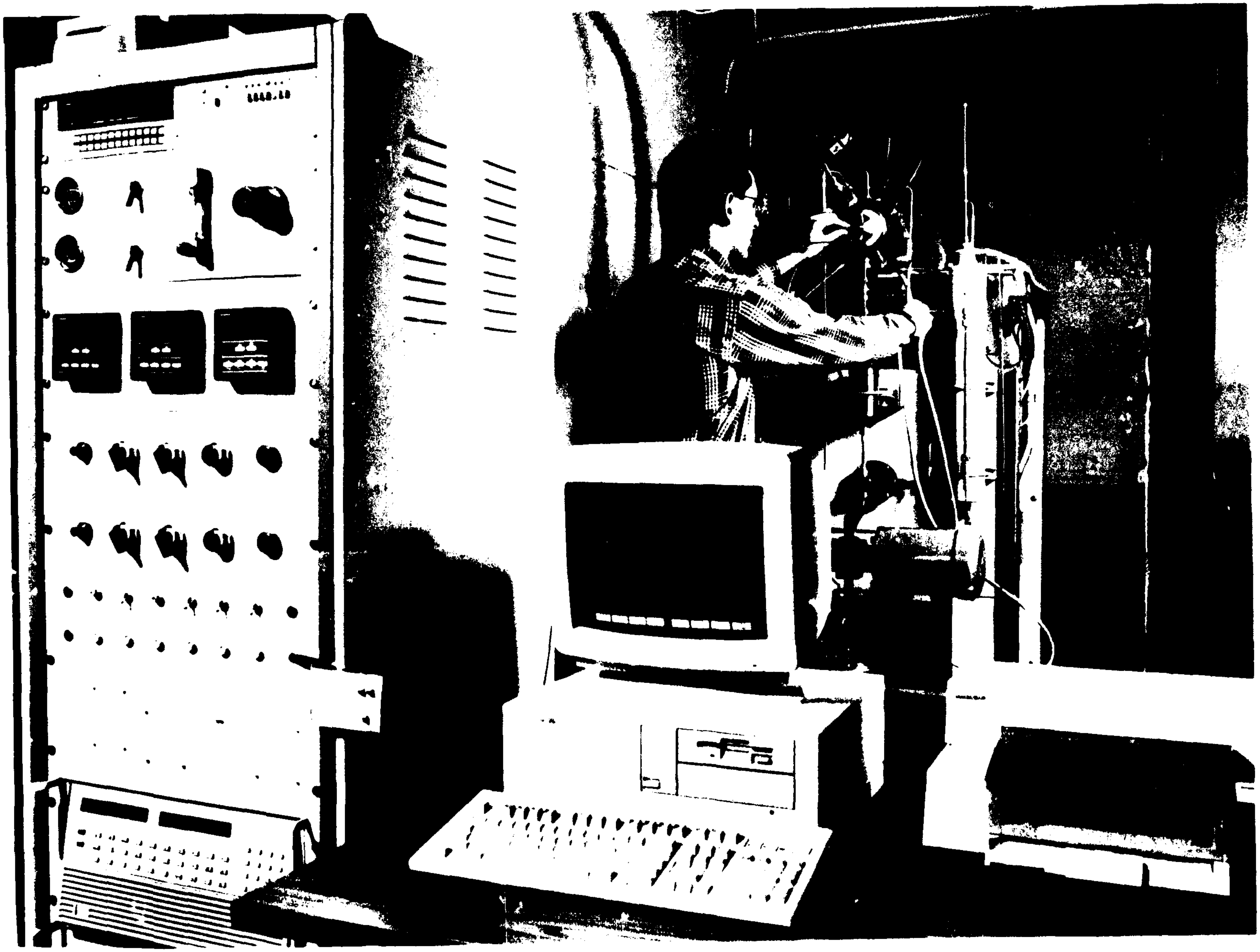

Figure 1. The MTELSS System

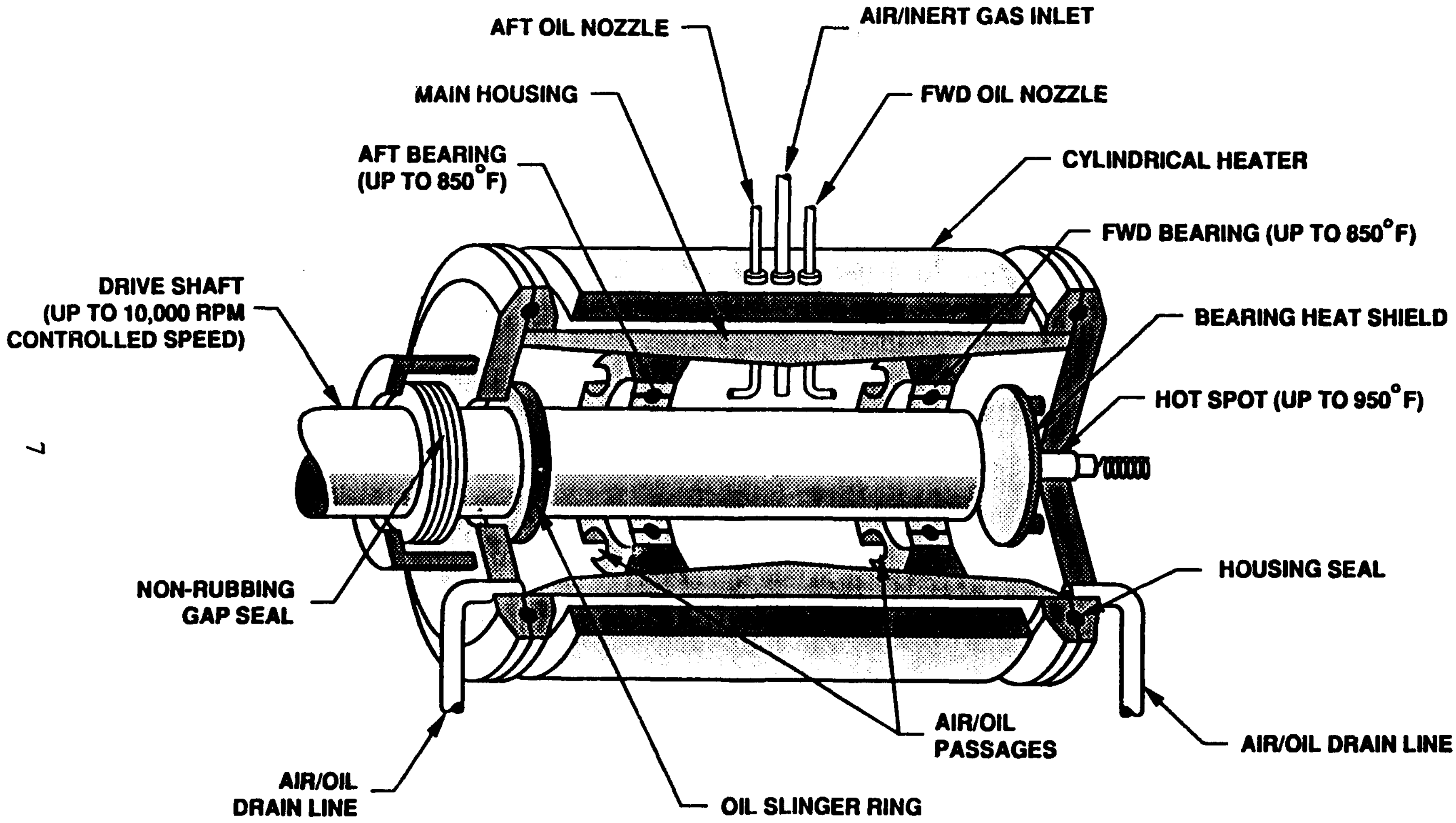

Figure 2. Design Concept of the MTELSS Test Section

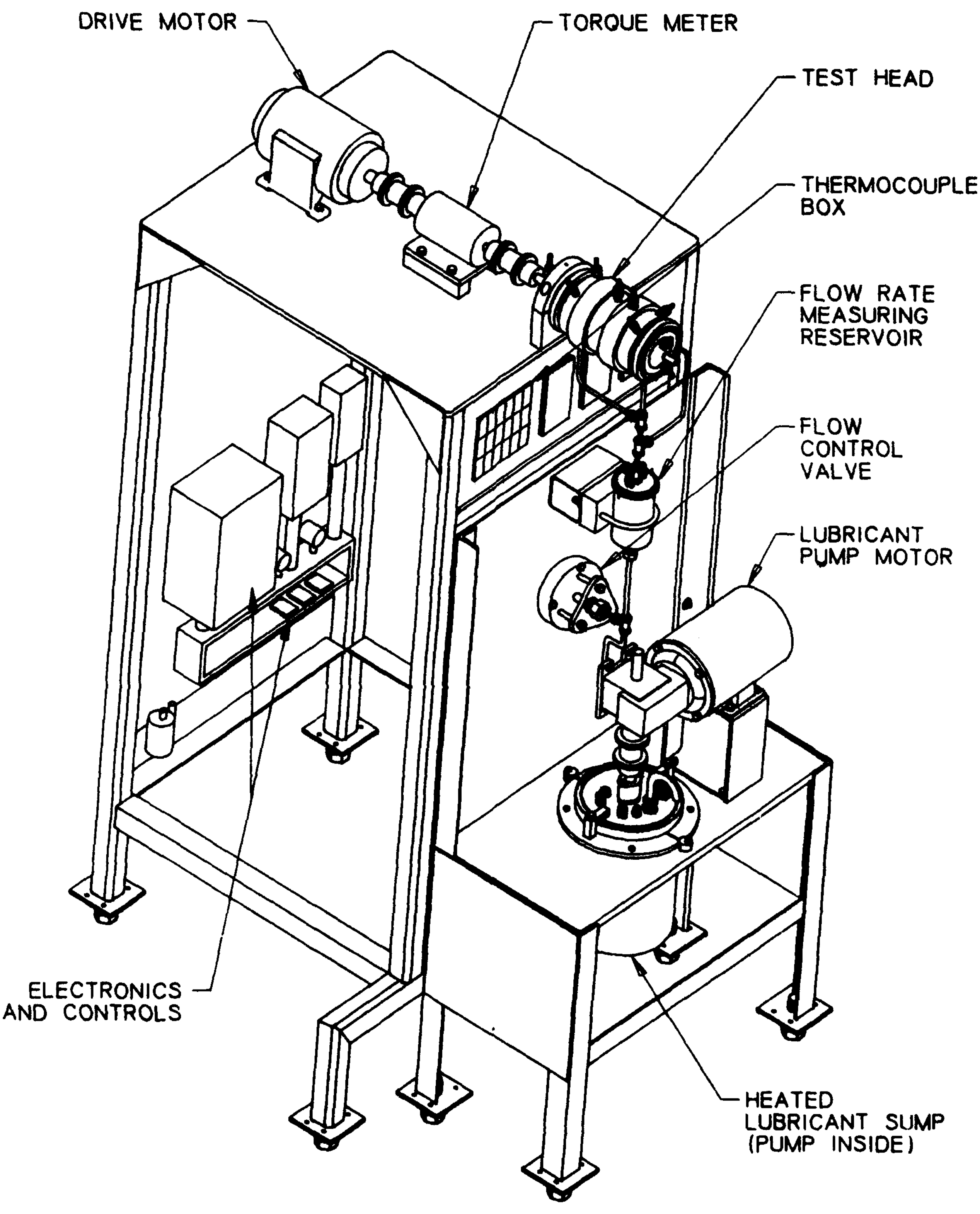

Figure 3. MTELSS Test Stand

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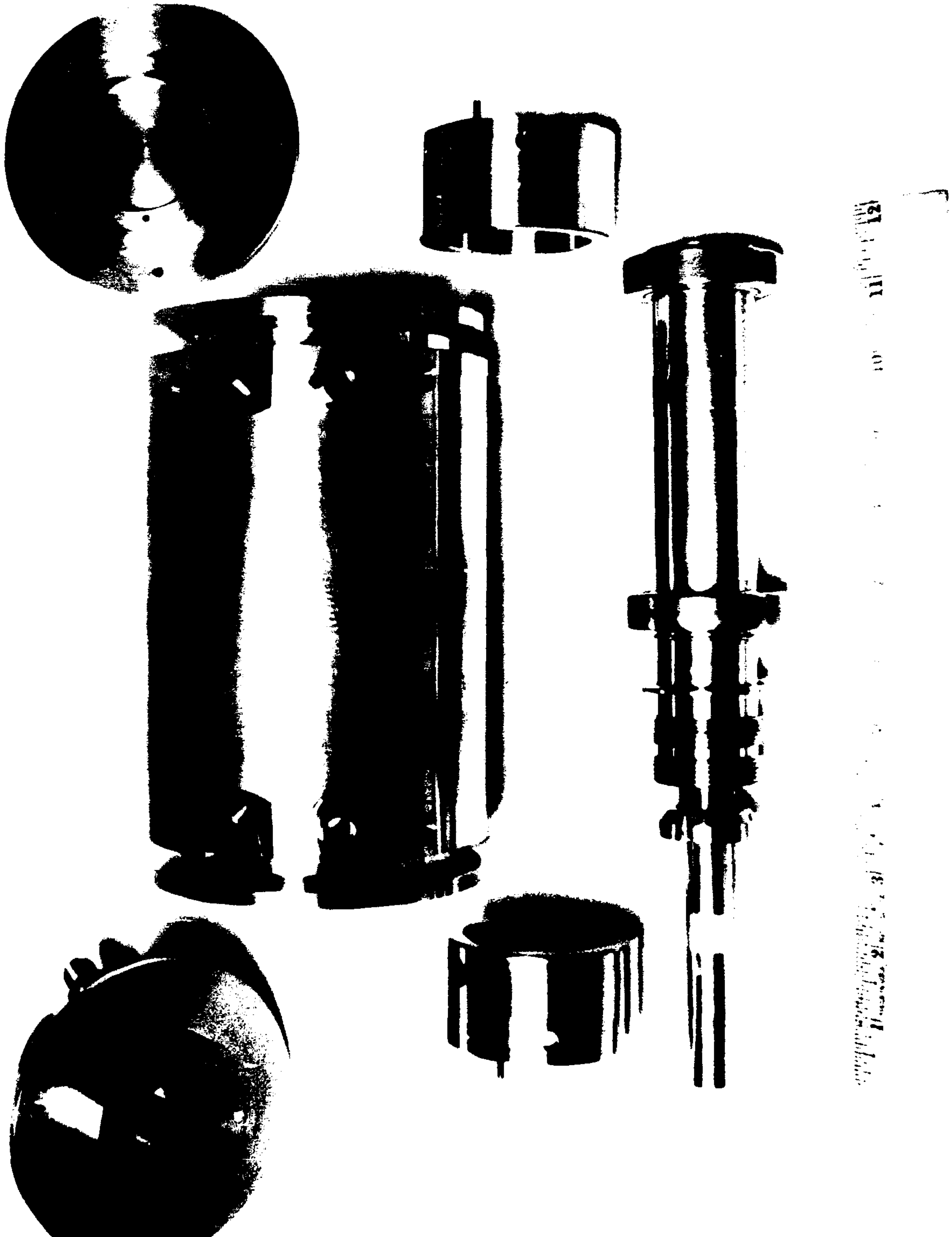


Figure 4. Major Components of the MTELSS Test Section

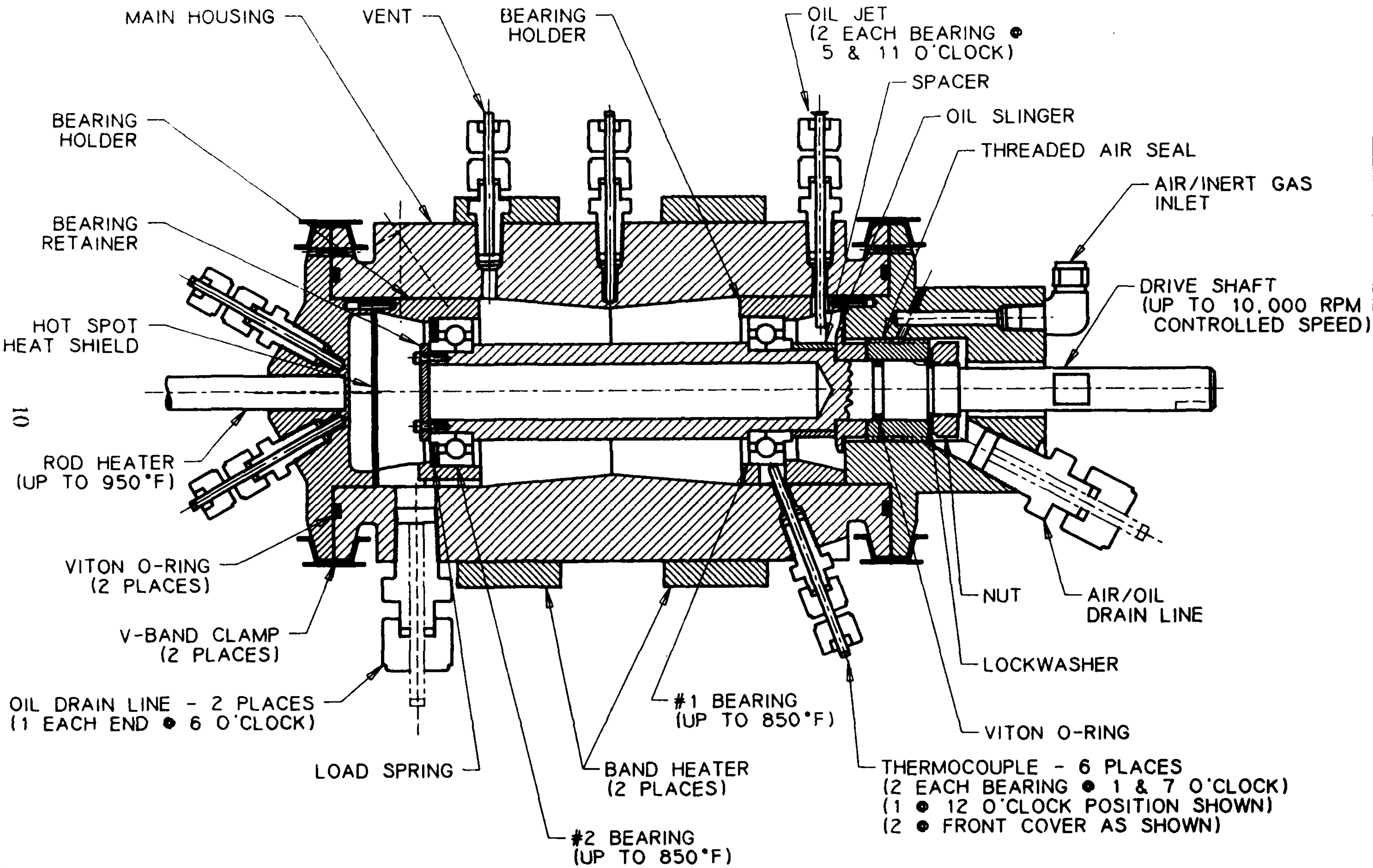


Figure 5. Assembly Drawing of the MTELSS Test Section

decision was based on discussions with personnel at the Corpus Christi Army Depot (CCAD) on the availability of bearings in the size range and the materials of construction. The balls and races of this bearing are made from M50 steel while the one-piece, outer ring riding cage is a silver-plated ASM-6415 steel. The bearing has a split inner race with a 30-mm bore, a 55-mm O.D., and 13 balls of 0.3125 in. diameter. These are the bearings that were used in the tests conducted as part of this project.

For test temperatures up to MTELSS design temperature of 850°F (455°C), six stellite bearings were specially made to the same dimensions given above by Split Ball Bearing Company and delivered to WPAFB for their use in further testing.

e. Drive Motor

The motor for the MTELSS drive system is a 3-hp electric motor with a variable frequency drive and operates over a speed range of 0 to 12,000 rpm. The speed and torque of the motor are measured by an in-line torque meter which is coupled to the drive motor and MTELSS drive shaft by double-jointed, flexible-disc couplings.

A non-rubbing gap seal is used to seal the drive shaft from the end plate of the test housing.

f. Lubricant Flow System

Figure 6 illustrates the flow system for the test lubricant. The system is designed to operate on one quart (0.95 liter) of fluid. As is typical with high-temperature test equipment, the pump is located in the sump. Provisions are made for small test specimens to be inserted into the sump to study corrosion and catalytic effects.

Hot oil is drawn from the bottom of the sump through a 100-mesh Inconel wire screen. From the pump, the test fluid passes through a 90-micron filter and then proceeds to the test head. Pressure transducers, isolated from the fluid by diaphragms, measure the pressure drop across the filter and the oil jets to determine if there is plugging; this is sensed by the computer, and the operator is alerted. A pressure drop across the filter of greater than 25 psi indicates that the filter is plugging excessively; if both pressures are rising, this means the jets are plugging. Inside the test head, the fluid is squirted directly onto each of the two test bearings in two places, at the top and bottom of each bearing about 30° off the vertical axis.

The fluid then drains from the head into a 200-ml reservoir that is used to determine the fluid flow rate. Originally it was planned to use a flow meter for this measurement, but one that was fabricated from a suitable material could not be found in the desired flow range. Instead, the flow rate is determined volumetrically. Under computer control, the return line from the test head is closed allowing the test fluid to accumulate in the reservoir. A thermocouple is used as a level sensor; there is a total of 260 ml of fluid in the unit when the level reaches the

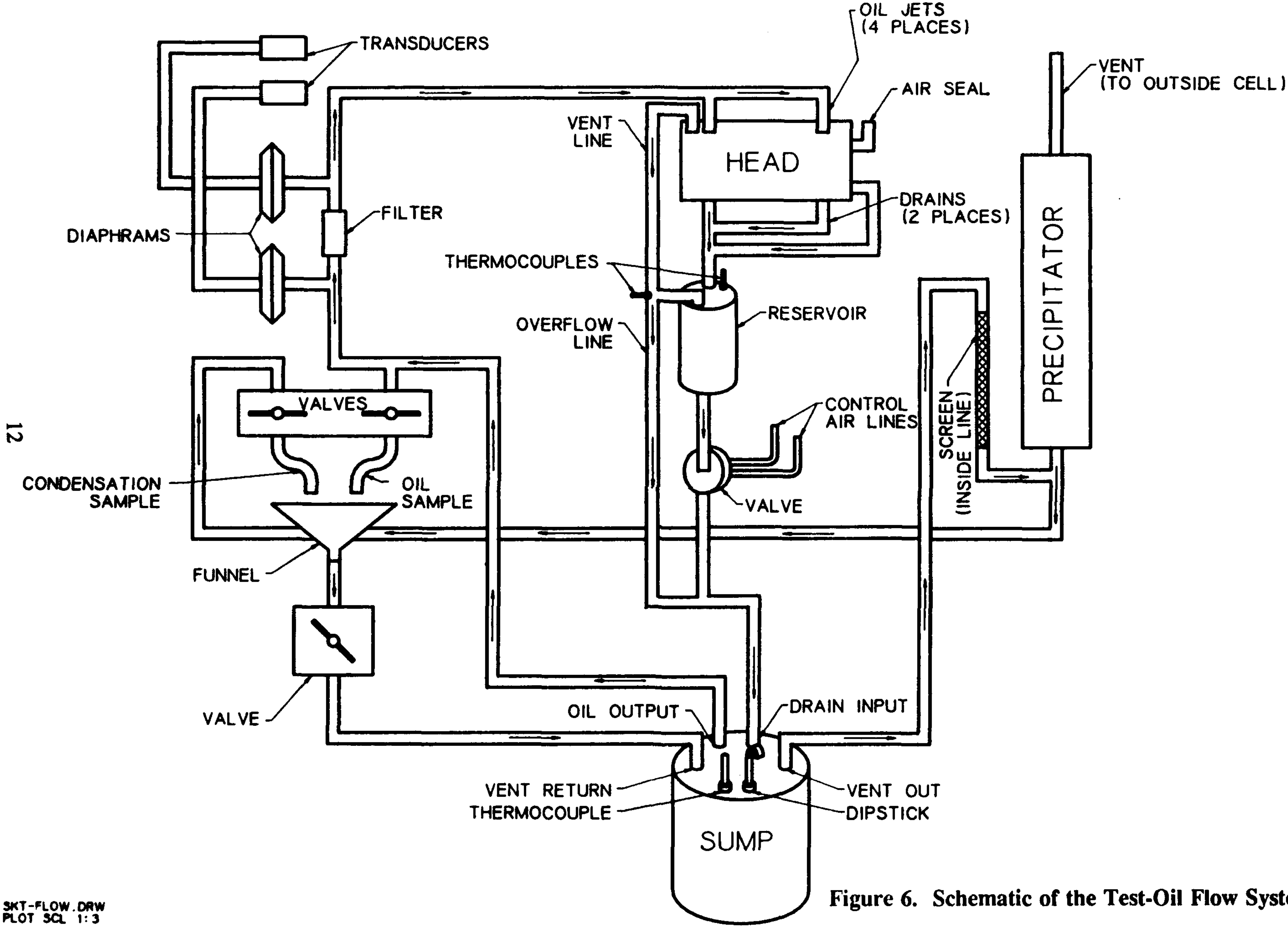


Figure 6. Schematic of the Test-Oil Flow System

thermocouple. The elapsed time is noted by the computer, and the flow rate calculated. At the same time the valve is opened and the fluid again drains directly into the sump.

It was necessary to vent the fluid drain line to the top of the test head to equalize pressures and facilitate draining. This was discovered during shakedown tests, and necessitated the use of the feed hole originally planned for the inert gas flow into the head. (Thus, as the system was delivered to WPAFB, it does not have a specific provision for inerting the test head; however, this can be easily accomplished by introducing the inert gas through the air-gap seal.)

The ullage of the sump is vented, but first all of test-fluid vapors are removed. The in-line screen acts as a de-mister to coalesce the droplets so they can drain back into the sump. The remaining test-fluid vapors and air that pass through this are directed to an electrostatic precipitator where the remaining oil is removed and returned to the sump. The cleaned air is then vented appropriately in the test cell to the atmosphere. The condensate as well as the fluid in the sump can be sampled for analysis. Provision is also made for adding makeup fluid to the system during a test.

(1) Sump: The sump houses the system pump and provides the heating source for the test fluid. Figure 7 is an assembly drawing of the sump. Figure 8 is a photograph of the pump supported from the top of the sump; at the bottom, mounted on the pickup, the six discs are coupons for materials compatibility/catalysis evaluation. The sump is heated by three external heaters controlling the bulk fluid temperature. The maximum sump temperature is 750°F (400°C). There are two band heaters on the outside of the sump, near the bottom, plus a disc heater on the bottom. In the area of the heaters, a 3/16-in. (0.5-cm) copper cladding has been placed under the heaters to improve heat distribution. For safety considerations, the sump sits in a stainless steel well. A thermocouple measures the sump temperature. The volume of fluid in the sump is measured with a dipstick; markings are at 1000, 1200, and 1600 ml. The sump cavity is connected to the top with a V-band coupling clamp to aid in disassembly for cleaning and inspection of the pump after a test.

The test coupons are mounted on a nickel-plated bolt covered by a 0.25-inch Inconel 600 sleeve. The coupons are shaped like washers with the dimensions 3/4" O.D., 1/4" I.D., and 1/16" thick. When mounted on the shaft, they are separated by Swagelock ferrules, also made of Inconel. The materials of the coupons would represent various oil-wetted materials of the engine; typical examples are silver, aluminum, titanium, Waspalloy, M50 steel, mild steel, and bronze.

(2) Lines: The lines from the sump to the head must be heated to maintain system temperature; this is especially important with the high-temperature lubricants which become very viscous as they cool and can plug the jets. This heating is done by wrapping the lines with heating tapes and then covering them with a ceramic-fiber insulating blanket such as Fiberfrax.

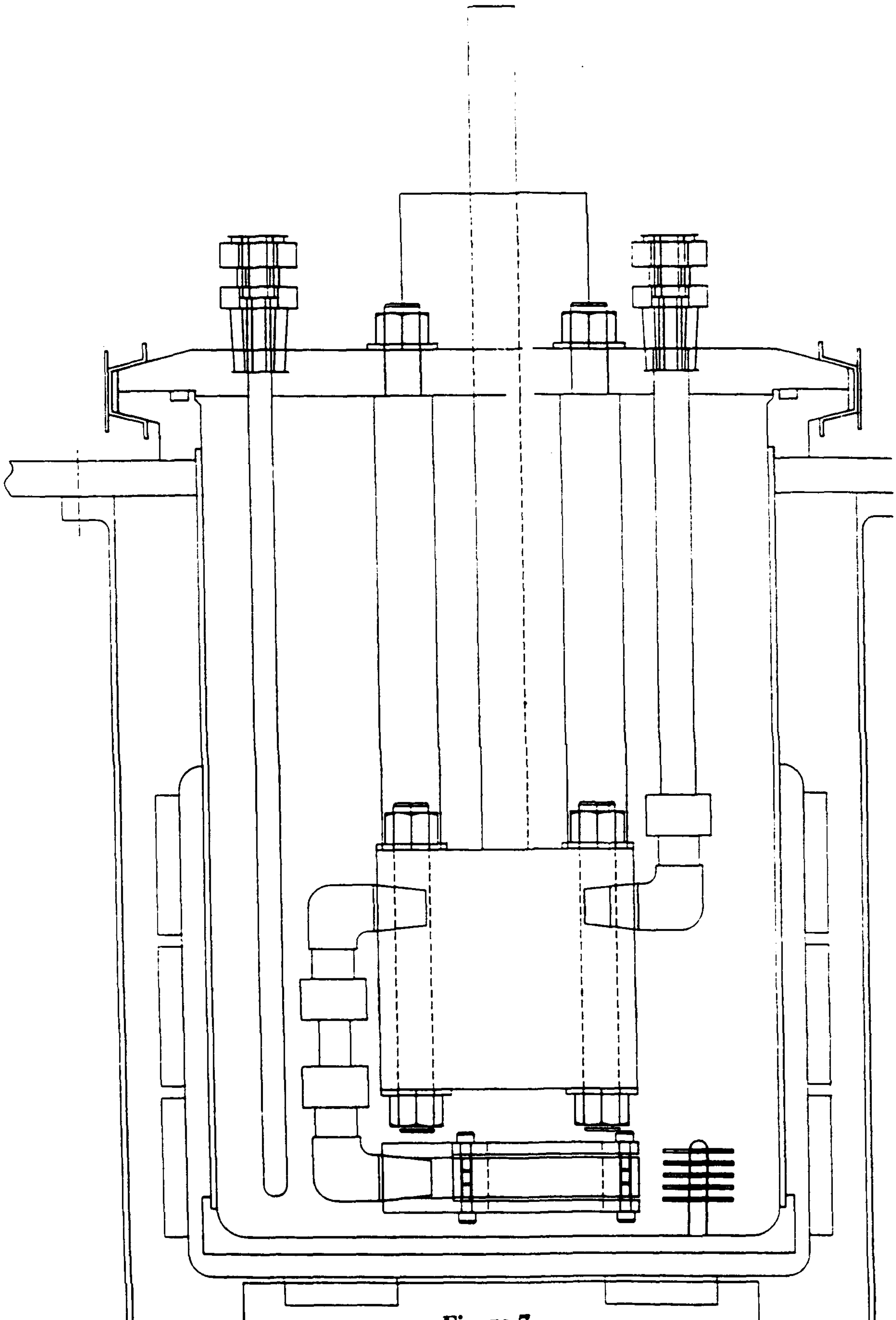


Figure 7.

Assembly Drawing of the Test-Oil Sump

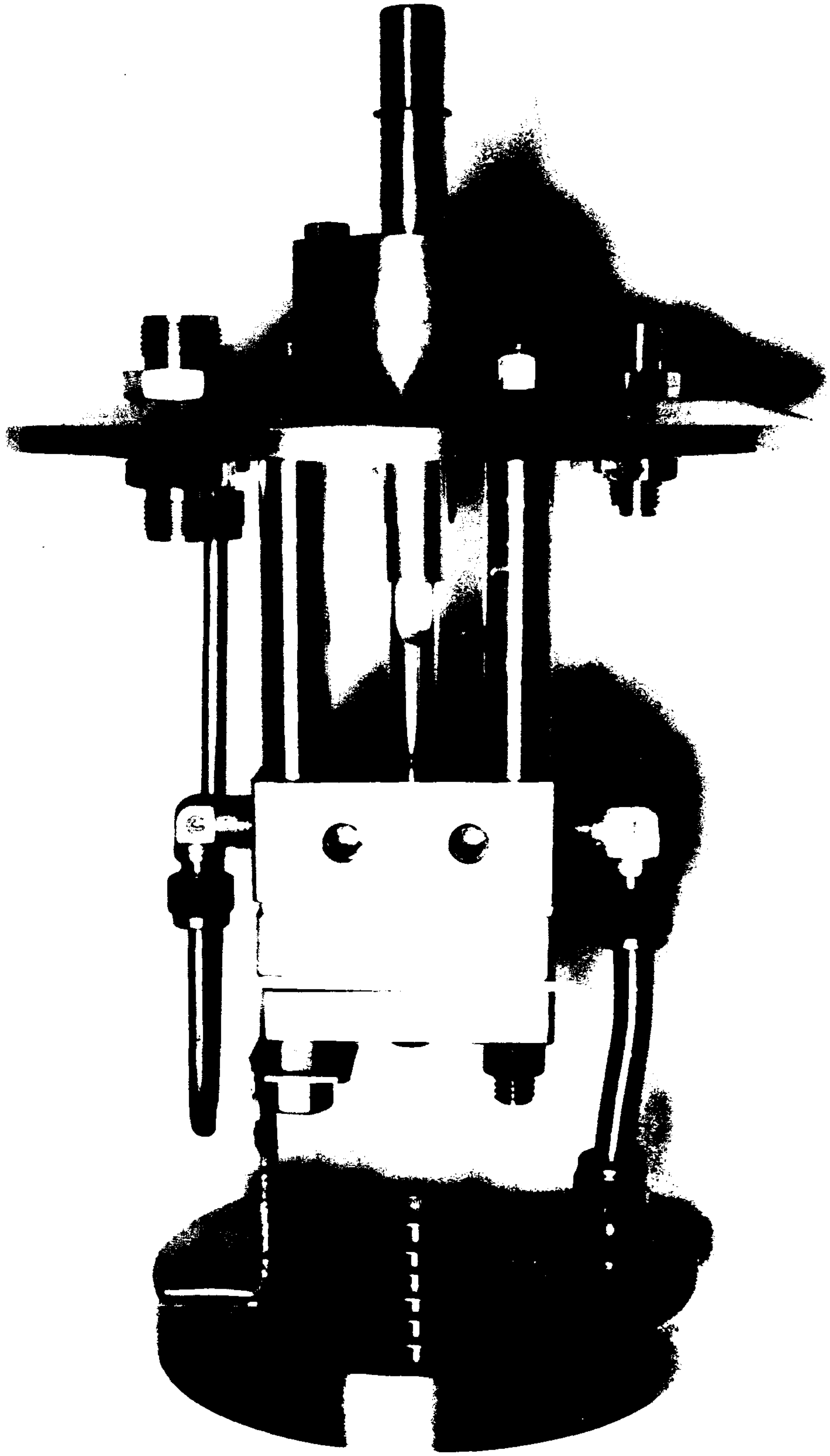


Figure 8. Test-Oil Pump and Test Coupons

(3) **Pump:** The test oil is circulated by a Zenith 30C-15701-C gear pump located in the sump. The pump has increased bearing clearances and is constructed from Hastelloy C-276 and Stellite 6B for high temperature and fluid compatibility. The pump delivers 4 ml/rev and can be run at 150 rpm for a maximum flow rate of 600 ml/min. The pump is driven through a 10:1 speed reducer by a 3/4-hp, 1800-rpm motor excited by a variable-frequency controller. A carbon seal is used where the pump drive shaft enters the test-oil sump.

(4) **Electrostatic Precipitator**: The electrostatic precipitator was designed and fabricated at SwRI from previous experience with flow systems of hazardous fluids. The purpose is to prevent any hazardous vapors from the sump to escape to the atmosphere. It consists simply of an 2-inch diameter cylinder with a 0.016-in. (0.04-cm) wire stretched along the centerline between an electrode at the top and an insulator at the bottom. This wire is charged to 10,000 volts a.c. The cylinder and wire are made of Inconel 600.

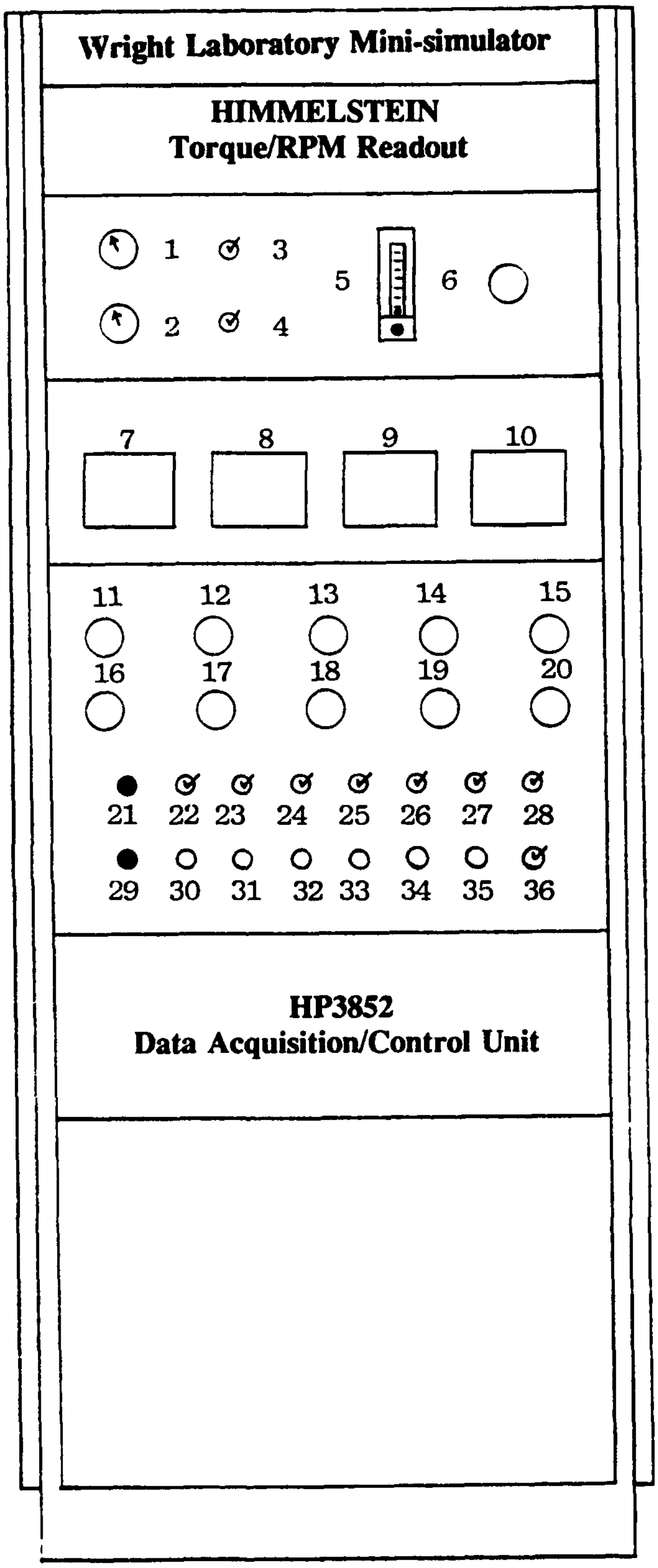
The basic principle is that when particles or aerosols are suspended in a gas they are exposed to gas ions in an electrostatic field, they become charged and migrate under the action of the field to a surface where they collect. The electrostatic field is set up between the charged wire and the grounded cylinder. The voltage on the wire is set high enough to achieve a corona discharge around the wire but not high enough to generate a spark. The corona discharge provides the necessary gas ionization. The aerosols migrate to the wall where they coalesce and drain to the bottom where they can flow back to the sump.

2. Control Console

All of the controls necessary for running a test with the MTELSS System are provided on the front of the Control Console; this consists primarily of the controls for the pump and drive motors, the heaters, the torque meter and the air as well as the data acquisition system. These are easily seen in Figure 1. Figure 9 is a schematic of the console identifying each of the items; the major features are described below and referenced by number to Figure 9.

At the top of the console is the Himmelstein MCRT 2402T control and readout unit for the torque meter. For this application, only the rpm and torque functions are used, but it is also possible to display horsepower.

The second panel contains the controls for the air supply which operates off the house air. The control on the right (Ref. #6) is the system pressure regulator. The two pressure gauges at the left indicate the line pressure of the house air (Ref. #2) and the regulated pressure (Ref. #1). The regulated pressure must be at least 25 psig to operate the shutoff valve for the flowrate measuring system. The air flow for the air seal in the test head is measured with the flowmeter seen just to the right of center. (Ref. #5) The switches (Refs. #3 and #4) control solenoid valves that provide regulated air to the shutoff valve and air seal, respectively.



1. Regulated Air to Solenoids, psi
2. House Air, psi
3. ON/OFF Switch to Solenoids
4. ON/OFF Switch to Air Seal
5. Air Seal Regulator
6. Solenoid Regulator
7. Hot Spot Heater Controller
8. #1 Bearing Heater Controller
9. #2 Bearing Heater Controller
10. Sump Heater Controller

DRIVE HEAD

11. Speed Control Potentiometer
12. ON/OFF Switch
13. CPU Bypass Switch
14. External Fault/Reset
15. Indicator Light

OIL PUMP

16. Speed Control Potentiometer
17. ON/OFF Switch
18. CPU Bypass Switch
19. External Fault/Reset
20. Indicator Light
21. Not Used
22. Power Supply 5 vdc
23. Precipitator
24. HP3852 DAC 110vac out
25. Hot Spot Heater
26. #1 & #2 Bearing Heaters
27. Sump Heater

FLOW MEASUREMENT SWITCHES

28. Manual/CPU
29. Not Used
30. Circuit Breaker
31. Circuit Breaker
32. Circuit Breaker
33. Circuit Breaker
34. Circuit Breaker
35. Circuit Breaker
36. Open/Closed

Figure 9. Schematic of MTELSS Control Console

The next (Ref. #7) panel contains the controls for the heaters, one each for the two test bearings, (Refs. #8 and #9) the hot spot, and the sump (Refs. #16 through #20). These provide for a manual override of the computer control for these motors as well as an indication of power failure. Below the motor controls is a row of switches (Refs. #22 through #28) for power to various elements of the system including the 5vdc regulated power for the pressure transducers (Ref. #22) and 110vac for the precipitator, (Ref. #23) the data acquisition system (Ref. #24) and the heater controllers. (Refs. #25 through #27) The circuit breaker for each switch is located directly below it. At the far right of these switches is the manual override (Ref. #28) for the test-fluid flowrate.

At the bottom of the control console is the Hewlett Packard 3852A Data Acquisition System which is controlled by the computer and is described in the next section. (C.3.)

The control console is connected to the MTELSS Test Stand by two overhead conduits; one contains all of the AC power lines while the other contains the control and data acquisition lines. All of the lines are shielded. Also the lines are numbered; Appendix A provides a summary of these lines, their function, and the elements they connect.

3. Computer and Data Acquisition System

(a) System Hardware

The data acquisition system is based on Hewlett-Packard (HP) equipment. Computer control is provided by an HP VECTRA PC with an internal BASIC LANGUAGE PROCESSOR (BLP) card. This combination provides not only PC compatibility, but also a programming environment that is optimized for data acquisition. Utilizing the ROCKY MOUNTAIN BASIC (RMB) programming language, the BLP card provides access to the HP 3852A Data Acquisition (DAQ) unit.

The HP 3852A data acquisition unit is also fully programmable in RMB. Additionally, the unit provides multi-tasking capabilities. These capabilities were utilized in the software in order to off-load the responsibilities from the computer controller. As configured, the HP 3852A DAQ unit has the following capabilities:

HP 3852 Capabilities

Thermocouple/Voltage Measurements	40 Channels
Strain Gauge Measurements	4 Channels
AC Control Relays	8 Channels
Digital to Analog Converter	4 Channels

The DAQ unit is used primarily to read temperatures and pressures. A Himmelstein MCRT 2402T unit is used to acquire speed and torque information. This unit is equipped with an IEEE-488 General Purpose Interface Bus (GP-IB) which is compatible with the HP equipment. It had been hoped that the speed and torque information could be acquired from the MCRT unit directly. Unfortunately, this was not possible. Instead, the raw voltage readings for these data are provided as inputs to the DAQ unit. The voltages are later converted to actual values by software in the system controller.

The operating conditions of the system, while under test, are displayed to the operator on a CRT. Figure 10 presents the display which the operator and includes the torque and speed of the test-bearing drive, the flow rate and system pressures of the test oil, and temperatures of various parts of the test system.

```
                         MTELSS Data Acquisition System

  Speed.....99999 RPM     Torque.....-99 lb-in      Flow Rate.....999 ml/MIN
Pressures
  Test Oil Before Filter.....99 Psig     Test Oil After Filter.....99 Psig
Temperatures
        Forward Oil Jets                                 Rear Oil Jets
  #1..99999 F    #2..99999 F                       #1..99999 F    #2..99999 F

        Forward Bearing                                  Rear Bearing
  #1..99999 F    #2..99999 F                       #1..99999 F    #2..99999 F

  Sump.........99999 F                             Resevoir TCs (Inactive)
  Hot Spot #1..99999 F        #2..99999 F          Lower.............99999 F
  Head.........99999 F                             Upper.............99999 F
                                                   Elapsed Time........999 S



  Channel out of range message area
  General Message Area

  F1     F2     F3     F4                   F5     F6     F7     F8
```

Figure 10. Operating Display

b) System Software

There are two software packages employed in the operation of the MTELSS: one to control the test parameters and acquire data, and one for data reduction and reporting. The details for operating these two packages are described in the Operator's Manual, which is Volume 2 of this report.

(1) Data Acquisition Software. As previously mentioned, the data acquisition software is written entirely in Rocky Mountain Basic. The software can be divided into two parts: controller software and DAQ unit software. The controller software is resident in the system controller during a test. The DAQ software is resident in the DAQ unit during a test but is loaded into the DAQ unit from the controller. Once the transfer is complete, the DAQ software is removed from the controller's memory.

The system software is contained in several files. The main file, named "MINILUB.HPB", controls the loading of the code modules at run-time. Each code module is designed to perform specific tasks, thus improving maintainability of the software. The module names as well as the task or tasks performed are given below:

MODULE NAME	DESCRIPTION
MINILUB.HPB	Main controlling module. Displays the introduction screen, allows the user to edit the test parameter information, and controls the loading of all code modules.
DISK_1O.HPB	Contains the subroutines To_disk and Openfile. To_disk used to log acquired data. Openfile creates the DOS file to which data are logged.
CONVERT.HPB	Applies appropriate conversion factors to the raw data.
GETPARMS.HPB	Contains subroutines to read the simulator parameter file which contains high/low limits, and control point indicators. Also contains subroutines used to allow modification to the parameter data.
FLORATE.HPB	Calculates the flow rate by determining how long it takes to fill a 260-ml container. The subroutine Calc_fr into not only performs the calculation, but also controls the opening and closing of the valves used to fill and empty the container.
GETDATA.HPB	This is the main workhorse during data acquisition. Data are retrieved from the DAQ unit through this module. All softkey functions are also controlled in this code module. In addition, the subroutine controls the auto-shutdown function as well as the display of the acquired data and the flow rate calculation.
SCREEN.HPB	This code module contains all subroutines that deal with the display of data. Subroutine Updscr displays acquired data on the screen. Subroutine Paintscr paints the display screen less the actual acquired data. Subroutine Load_xy loads the screen coordinates for each of the displayed data points.
LOADAQ.HPB	This module is called once to load the DAQ unit with programs used to take data. Two tasks are downloaded. The first is used to scan the logged data

channels, whereas the second is used to scan the channels used to calculate the flow rate.

(2) Data Reduction and Reporting Software. Data reduction is accomplished by executing a DOS program written in the FORTRAN programming language. This program takes the raw output files created by the data acquisition software and produces general statistics for each of the logged channels with the exception of the elapsed time. Summaries can be produced for a single 16-hour test segment or for all test segments. If all test segments are requested, then a summary of the combined test segments is also produced. Appendix B contains a sample of the output produced by the data reduction software.

Data reports are produced by utilizing the QUATTRO PRO spreadsheet package. A set of preprogrammed macros guides the user through all the phases of data input and output. A sample test report and graphs are contained in Appendix C.

D. TEST PROCEDURE

1. Overview

The basic methodology of the MTELSS system lubricant evaluation consists of a 48-hour test at the prescribed temperatures followed by a visual rating of the deposits found on the fluid-wetted parts of the test head. Metal test coupons can be evaluated for metal loss during the test. The specific details of operating the MTELSS Test Rig are given in the Operator's Manual which is Volume 2 of this report. Also presented in Volume 2 are the specific procedures for tear-down and reassembly of the system.

At the end of a test, the computer will produce a test report which summarizes the temperature profile of the test and the lubricant performance. Lubricant performance data consist of viscosity and neutralization number in addition to the deposit demerits and the corrosion of the metal coupons; the data are not generated by the computer but are input by the operator after evaluations have been completed.

2. Deposit Rating Procedure

The deposit rating method for the MTELSS follows the procedure of lubricant specification MIL-L-27502. The cleanliness of the parts is reported in a deposit demerit system by the assignment of values of 0 to 20 to identify the different types and thicknesses of deposits as follows: 0 designates a new or clean condition; 20 represents the worst condition that could be expected. Table 1 presents the numerical demerits to be assigned to the different types and degrees of deposits. Table 2 defines the deposit types and the severities.

TABLE 1. DEMERIT RATING NUMBERS USED FOR NUMERICALLY DESCRIBING DEPOSITS

	Demerit Rating Number		
Deposit Type	Light	Medium	Heavy
Varnish	1	3	5
Sludge	6	7	8
Smooth carbon	9	10	11
Crinkled carbon	12	13	14
Blistered carbon	15	16	17
Flaked carbon	18	19	20

TABLE 2. DESCRIPTION OF DEPOSIT TYPES AND DEGREES

Deposit Type	Degree	Description
Varnish	---	Varnish or lacquer-like coating, shiny
	Light	Light gold or yellow in color, translucent
	Medium	Brown or dark brown in color, translucent
	Heavy*	Black in color, opaque
Sludge	---	Shiny, oily emulsion of carbon and oil, usually light brown in color; removable by wiping with a rag
	Light	Less than 1/64-in. thickness
	Medium	1/64 to 3/64-in. thickness
	Heavy	3/64-in. thickness or more
Smooth carbon	---	Carbonaceous coating not removable by wiping with a rag
	Light*	Less than 1/64-inch thickness
	Medium	1/64 to 3/64-inch thickness
	Heavy	3/64-inch thickness or more
Crinkled carbon	---	Same as for smooth carbon, ridged or uneven surface; not smooth
	Light	Less than 1/64-inch thickness
	Medium	1/64 to 3/64-inch thickness
	Heavy	3/64-inch thickness or more
Blistered carbon	---	Same as for smooth carbon, blistered, bubbled
	Light	Less than 1/64-inch thickness
	Medium	1/64 to 3/64-inch thickness
	Heavy	3/63-inch thickness or more
Flaked carbon	---	Same as for smooth carbon, flaked or broken blisters, peeling
	Light	Less than 1/64-inch thickness
	Medium	1/64 to 3/64-inch thickness
	Heavy	3/64 thickness or more

* Some difficulty may be encountered in distinguishing between light smooth carbon deposit and heavy varnish. The varnish deposit appears shiny and glossy and upon scraping indicates a tacky consistency or thin, brittle flaking. The smooth carbon deposit appears dull and lusterless and upon scraping reveals a grainy consistency.

In the MTELSS methodology, the following twelve items from the test head are visually rated to develop the overall result in the demerit rating methodology:

- Two end covers (#1 and #2) - The inner surface normally exposed to the test oil
- Test housing - The inner surface between the bearing holders
- Hot-spot heat shield - Average rating of the front and back sides
- Drive shaft - The surface area between the test bearings
- Bearing retainer - The front side, normally exposed to the test oil
- Oil slinger - The entire outer surface exposed to the test oil
- Spacer - The entire outer surface
- Two bearing mounts (#1 and #2) - The I.D. and the face normally exposed to the test oil; the ratings for these two surfaces are averaged
- Two test bearings (#1 and #2) - The test bearings are divided into four sections for rating purposes; these four sections are further broken down into eight specific areas as follows:

• Balls	1. surface
• Cage	2. front face
	3. rear face
• Inner race	4. front face
	5. rear face
	6. contact surface
• Outer race	7. front face
	8. rear face

Note: If the balls are separable from the outer race, then that contact surface should also be rated adding a ninth area to the bearing rating.

A rating for each inspected item is obtained by multiplying the so-called "area demerit rating" by the demerit value assigned in Table 1 and summing all such results to account for 100% of the area of the item being inspected. The "area demerit rating" is simply defined as follows:

$$\frac{\text{percent area covered}}{10} = \text{"area demerit rating"}$$

Surface deposits are not normally divided into areas of less than 5%.

In the event that more than one type of deposit is present on the area being inspected, the rating for that area or item is the total of the individual rating values. The deposit rated is that which is visible without the removal of another deposit. Double ratings, such as sludge over varnish, are not used. The ratings for the test bearings are obtained by taking the sum of the eight rated areas and dividing by eight. (Note: This would be nine if the balls are separable from the outer race so that the outer contact area can be rated.)

The demerit rating for each major item is determined by multiplying the rating obtained above by an assigned weighting factor which is given in Table 3.

TABLE 3. ASSIGNED WEIGHTING FACTORS FOR RATED TEST ITEMS

Major Item	Rating	Factor	Demerits
#1 End Cover	X_1	1	X_1
#2 End Cover	X_2	1	X_2
Test Housing	X_3	2	$2X_3$
Hot Spot Shield	X_4	3	$3X_4$
Drive Shaft	X_5	2	$2X_5$
Bearing Retainer	X_6	2	$2X_6$
Oil Slinger	X_7	1	X_7
Spacer	X_8	1	X_8
#1 Bearing Mount	X_9	3	$3X_9$
#2 Bearing Mount	X_{10}	3	$3X_{10}$
#1 Test Bearing	X_{11}	5	$5X_{11}$
#2 Test Bearing	X_{12}	5	$5X_{12}$

The final overall deposit rating for the oil is the sum of the demerits for the major items divided by 12.

After the test, the interior wall and bottom of the test-oil sump are inspected and rated. This rating is not included in the determination of the overall test rating, but is reported in terms of the type of surface deposits present and the area covered by each deposit type rather than numerical demerits.

3. Metal Test Coupons

Prior to the test, the test coupons are rinsed in a clean solvent such as heptane or toluene, air dried, and weighed to the nearest 0.1 mg. Following the test, the coupons are again cleaned and weighed. Significant weight change is reported in mg/cm^2 ignoring edge areas in the calculation of exposed surface area. A significant weight change is defined as a weight variation of $\pm$ 0.20 mg/cm^2 or more.

4. Cleaning Procedure

After the rating procedure has been completed, <u>all</u> parts which come in contact with the test fluid are cleaned with the exception of the filter which is a throw-away item.

First, the parts are rinsed with a solvent such as heptane or toluene to remove excess test fluid. All parts with any deposits are to be cleaned by immersion in a hot caustic bath; a circulated bath is best as it helps to lift the deposits and wash them away. Light deposits should take about 30 minutes; heavy deposits may take 2 to 3 hours.

The parts are then rinsed with tap water and scrubbed with a mild cleanser like Ajax or Comet using a non-abrasive scouring pad like Scotch-Brite. The parts are thoroughly rinsed with tap water after all deposits are removed. (Note: Wear rubber gloves to avoid getting fingerprints on rating surfaces as they affect the deposits.)

Next the parts are submerged in a metal-brightening solution, e.g., ZEP Formula 7961, for 15-30 minutes to restore the surface shine. They are then removed and scrubbed again with the mild cleanser, rinsed with tap water, and air dried.

There are a few parts which are not cleaned with caustic: the diaphragms, the jets, and the electrode and wire from the precipitator. The diaphragms and precipitator pieces are simply washed with solvent and air dried. The jets are not cleaned in the caustic bath because there may be debris floating in the bath which can get inside the jets and clog the small flow passages. Instead they are submerged in heated chromic acid after rinsing in the solvent; following this, they are reamed with a piece of fine wire while flushing with tap water.

E. TESTS AND RESULTS - TASK 4

Four tests were conducted as part of this project. The first two were conducted at SwRI before the delivery of the MTELSS System to WPAFB; the last two were conducted at WPAFB as part of the training program for personnel at WPAFB on the operation of the System. Table 4 summarizes the lubricants and test conditions for these four tests; the tests conducted at WPAFB were repeats of the tests conducted at SwRI. (Test No. 1 was invalidated because of a leak resulting in an excessive loss of fluid.)

TABLE 4. SUMMARY OF TEST LUBRICANTS AND CONDITIONS

Test	Test Location	Lubricant	Type	Bearing Temperature	Lubricant Temperature	Tables f/Reports
2	SwRI	MIL-L-7808 TEL-90081	Synthetic	500°F	350°F	5 and 6
3	SwRI	MIL-L-87100 TEL-90083	5P4E	680°F	572°F	7 and 8
4	WPAFB	MIL-L-7808 Code 0-087-2B	Synthetic	500°F	350°F	9 and 10
5	WPAFB	MIL-L-87100 TEL-90083	5P4E	680°F	572°F	11 and 12

MTELSS Test 2 was the first complete test on the MTELSS using a standard MIL-L-7808 lubricant. Table 5 summarizes the test conditions and the deposit ratings. The overall rating of the lubricant is 76.9; this number would be relatively high if obtained on the standard 7808 bearing deposition test. However, it is possible that this could be a result of the rating factors assigned for the various MTELSS components. It was not within the scope of this program to massage the rating scheme to make the MTELSS methodology for a 7808 lubricant agree with the standard procedure; this would require the running of a number of tests to determine the variability of the MTELSS system and then alter the ratings accordingly to equalize the relative severity between the tests. Table 6 summarizes the lubricant degradation during the test and the results of the metal corrosion tests. The viscosity increase was slight and well within the 25% allowed in the standard 7808 bearing deposition test. The neutralization number at 48 hours was also within the allowable, but just barely (1.4 compared to 1.5 mg KOH/g limit).

MTELSS Test 3 was conducted on a 5P4E lubricant; the sump and lubricant temperatures were higher than for Test 2 because this is a high-temperature lubricant. During this test it discovered that at these temperatures there was a significant variance in the bearing temperatures

TABLE 5. RESULTS FROM MTELSS TEST NO. 2

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT TEL-90081			
DEPOSIT DEMERITS			
ITEM	RATING	FACTOR	DEMERITS
No. 1 End Cover	9	1	9
No. 2 End Cover	33	1	33
Housing ID	97.5	2	195
Hot Spot	67	3	201
Drive Shaft	33.5	2	67
Bearing Retainer	0	2	0
Slinger	0	1	0
Spacer	0	1	0
No. 1 Bearing Mount	39.5	3	118.5
No. 2 Bearing Mount	51.5	3	154.5
No. 1 Bearing	15	5	75
No. 2 Bearing	13.75	5	68.8
TOTAL			922.8
Overall Rating: $\frac{922.8}{12} = 76.9$			
Not included in rating: Sump - wall 100% clean; bottom 100% clean			
Oil consumption, mℓ/hr	7.9		
Accumulated filter wt, g	0.15		
Sump temperature, °F	350		
Bearing temperature, °F	500		
Hot spot temperature, °F	unheated		
Test duration, hr	48		

TABLE 6. RESULTS FROM MTELSS TEST NO. 2
(Cont'd.)

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT TEL-90081			
LUBRICANT PERFORMANCE			
Test Time, hr	Viscosity, cSt @ 104°F	Viscosity Change, %	Neut. No., mg KOH/g
0	12.34	-	0.41
4	12.35	0.1	0.41
8	12.50	1.3	0.41
12	12.63	2.4	0.41
16	12.78	3.6	0.58
20	12.77	3.5	0.64
24	12.92	4.7	0.82
28	12.96	5.0	0.94
32	13.08	6.0	0.94
36	13.02	5.5	0.94
40	12.99	5.3	1.05
44	13.01	5.3	1.41
48	13.16	6.6	1.41

Metal Corrosion Data	
Metal	Weight Change, mg/cm^2
Al	0.0
Ag	0.0
Mild steel	+0.02
M-50	0.0
Waspaloy	0.0
Ti	0.0

which could not be corrected by adjusting the insulation. With No. 2 bearing controlled to 680°F (360°C), No. 1 bearing stabilized at 650°F (343°C). The problem was caused by the initial assumption that only one controller would be necessary for the heaters in the Test Head. As a result of this problem, the system was modified, and another heater controller was installed to permit individual temperature control on the test bearings.

Tables 7 and 8 summarize the results of Test 3. The overall deposit rating of 75.2 is comparable to the value obtained in Test 2 with the 7808 lubricant. In terms of the standard bearing deposition test, a rating in the mid-70's should appear somewhat severe; however, a direct comparison is probably not appropriate because of the differences in the number and types of components rated as well as differences in the heat transfer for the various components which would influence their surface temperatures and deposits.

The lubricant performance for this test showed a modest increase in viscosity of 17.1% at 48 hours. Both the viscosity increase and the change in neutralization number were within the allowable for MIL-L-87100, the 5P4E specification.

MTELSS Test 4 was conducted after the mini-simulator was installed at WPAFB. This test was conducted on a 7808 oil to compare with Test 2 conducted at SwRI. The results are presented in Tables 9 and 10. The overall deposit rating of 78.7 agrees very well with the rating of 76.9 obtained in Test 2. The ratings for the hot spot and the No. 2 End Cover are much lower than in Test 2 because the hot spot was not turned on in this test because the controller was temporarily being used for the heater on Bearing No. 2. Most of the other individual ratings seem about the same. The lubricant loss during the test was much less than in Test 2 due to general tightening of the system. The lubricant performance was within the specification limits.

MTELSS Test 5 was conducted on the 5P4E lubricant as a comparison with Test 3. The results are summarized in Tables 11 and 12. The overall deposit rating is significantly higher than that of Test 3. The two bearing mounts are primarily responsible for this increase. The temperatures of the bearings and the test head were higher in this test than in Test 3 because of the additional temperature controller discussed above; there was more of a change here than between the 7808 tests because the overall temperatures were higher. It is felt that Test 5 is probably more representative of the performance of a 5P4E oil than Test 3.

F. SUMMARY

A unique, Miniaturized Turbine Engine Lubrication System Simulator (MTELSS) to evaluate advanced lubricants under high-temperature conditions has been designed, fabricated, and tested. The mini-simulator meets all of the design goals. It provides a ball bearing test at 10,000 rpm and 100,000 psi Hertz stress at lubricant temperatures up to 750°F (400°C). The bearings can be heated to 850°F (455°C), and a hot spot is provided that can be controlled to 950°F (510°C). The system can operate on 1.0 quart (1.0 liter) of test fluid. It is fabricated almost entirely from Inconel, and is compatible with all known lubricant candidates including polyphenyl ethers and

TABLE 7. RESULTS FROM MTELSS TEST NO. 3

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT TEL-90083			
DEPOSIT DEMERITS			
ITEM	RATING	FACTOR	DEMERITS
No. 1 End Cover	1	1	1
No. 2 End Cover	29	1	29
Housing ID	76.5	2	153
Hot Spot	25.5	3	76.5
Drive Shaft	20	2	40
Bearing Retainer	10	2	20
Slinger	0	1	0
Spacer	0	1	0
No. 1 Bearing Mount	28.5	3	85.5
No. 2 Bearing Mount	63.5	3	190.5
No. 1 Bearing	22.9	5	114.5
No. 2 Bearing	38.6	5	193
TOTAL			903
Overall Rating: $\frac{903}{12} = 75.2$			
Not included in rating: Sump - wall 100% clean bottom 100% clean			
Oil consumption, mℓ/hr	0.4		
Accumulated filter wt, g	Not used		
Sump temperature, °F	572		
Bearing temperature, °F	680		
Hot spot temperature, °F	unheated		
Test duration, hr	48		

TABLE 8. RESULTS FROM MTELSS TEST NO. 3
(Cont'd.)

48-HOUR MINISIMULATOR SUMMARY DATA FOR LUBRICANT TEL-90083			
LUBRICANT PERFORMANCE			
Test Time, hr	Viscosity, cSt @ 104°F	Viscosity Change, %	Neut. No., mg KOH/g
0	276.1	-	0.27
4	281.1	1.8	0.23
8	289.2	4.7	0.22
12	289.4	4.8	0.15
16	298.0	7.9	0.19
20	294.3	6.6	0.14
24	300.4	8.8	0.12
28	297.3	7.7	0.15
32	297.5	7.8	0.20
36	314.1	13.8	0.16
40	338.9	22.7	0.25
44	327.0	18.4	0.18
48	323.3	17.1	0.18

Metal Corrosion Data	
Metal	Weight Change, mg/cm^2
Al	+0.02
Ag	+0.02
Mild steel	+0.06
M-50	+0.02
Waspaloy	+0.02
Ti	+0.02

TABLE 9. RESULTS FROM MTELSS TEST NO. 4

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT MIL-7808 (Code: 0-087-2B)			
DEPOSIT DEMERITS			
ITEM	RATING	FACTOR	DEMERITS
No. 1 End Cover	11	1	11
No. 2 End Cover	10	1	10
Housing ID	179.5	2	359
Hot Spot	12.5	3	37.5
Drive Shaft	45	2	90
Bearing Retainer	9	2	18
Slinger	0	1	0
Spacer	0	1	0
No. 1 Bearing Mount	33	3	99
No. 2 Bearing Mount	38.5	3	115.5
No. 1 Bearing	15.63	5	78.15
No. 2 Bearing	25.3	5	126.5
TOTAL			944.65
Overall Rating: $\frac{944.65}{12} = 78.72$			
Not included in rating: Sump - wall 100% clean; bottom 100% clean			
Oil consumption, mℓ/hr	3.0		
Accumulated filter wt, g	0.0712		
Sump temperature, °F	350		
Bearing temperature, °F	500		
Hot spot temperature, °F	unheated		
Test duration, hr	48		

TABLE 10. RESULTS FROM MTELSS TEST NO. 4
(Cont'd.)

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT ML-7808 (Code: 0-087-2B)			
LUBRICANT PERFORMANCE			
Test Time, hr	Viscosity, cSt @ 104°F	Viscosity Change, %	Neut. No., mg KOH/g
0	12.33	-	0.01
1 hr, 15 min	12.26	-0.07	0.02
4	12.32	-0.1	0.07
8	12.72	0.39	0.24
12	12.85	0.52	0.53
16	13.00	0.67	0.95
20	13.00	0.67	1.04
24	13.18	0.85	1.64
28	13.33	1.0	2.27
32	13.49	1.16	2.61
36	13.61	1.28	2.90
40	13.65	1.32	3.23
44	13.94	1.61	3.64
48	13.90	1.57	3.86

Metal Corrosion Data	
Metal	Weight Change, mg/cm^2
Al	-0.02
Ag	-0.06
Mild steel	-0.04
M-50	-0.02
Waspaloy	0
Ti	-0.02

TABLE 11. RESULTS FROM MTELSS TEST NO. 5

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT POLYPHENYL ETHER (TEL-90083)			
DEPOSIT DEMERITS			
ITEM	RATING	FACTOR	DEMERITS
No. 1 End Cover	32	1	32
No. 2 End Cover	42	1	42
Housing ID	52	2	104
Hot Spot	50.5	3	151.5
Drive Shaft	28	2	56
Bearing Retainer	10	2	20
Slinger	7.5	1	7.5
Spacer	7.5	1	7.5
No. 1 Bearing Mount	84.25	3	252.75
No. 2 Bearing Mount	128.25	3	384.75
No. 1 Bearing	30	5	150
No. 2 Bearing	31.88	5	159.4
TOTAL			1367.4
Overall Rating: $\frac{1367.4}{12} = 113.95$			
Not included in rating: Sump - wall 100% clean bottom 100% clean			
Oil consumption, mℓ/hr	1.98		
Accumulated filter wt, g	Not used		
Sump temperature, °F	572		
Bearing temperature, °F	680		
Hot spot temperature, °F	unheated		
Test duration, hr	48		

TABLE 12. RESULTS FROM MTELSS TEST NO. 5
(Cont'd.)

48-HOUR MINISIMULATOR TEST SUMMARY DATA FOR LUBRICANT POLYPHENYL ETHER (TEL-90083)			
LUBRICANT PERFORMANCE			
Test Time, hr	Viscosity, cSt @ 104°F	Viscosity Change, %	Neut. No., mg KOH/g
0	277.28	-	Not reported
4	279.02	0.6	Not reported
8	284.24	2.5	Not reported
12	288.48	4.0	Not reported
16	293.11	5.7	Not reported
20	294.04	6.0	Not reported
24	296.32	6.9	Not reported
28	302.92	9.2	Not reported
32	306.91	10.7	Not reported
36	308.05	11.1	Not reported
40	312.01	12.5	Not reported
44	315.86	13.9	Not reported
48	320.07	15.4	Not reported

Metal Corrosion Data	
Metal	Weight Change, mg/cm^2
Al	-0.02
Ag	0
Mild steel	+0.02
M-50	+0.02
Waspaloy	0
Ti	-0.02

the atmosphere can be inerted. The system is under computer control, and all operating parameters are continuously monitored.

The MTELSS has been successfully installed and demonstrated at Wright-Patterson Air Force Base in Building 490 in compliance with all pertinent safety, health, and operational regulations. Personnel at WPAFB were trained in the test procedures including the rating and cleaning of parts and the reassembly of the MTELSS.

G. RECOMMENDATIONS

It is recommended that a number of tests be performed on a 7808 oil to develop the repeatability of the methodology and to determine the significance of the rating as compared to the standard 7808 bearing deposition test. It may be desirable to modify the factors for the various items to establish a rating consistent with earlier methodologies.

APPENDIX A
IDENTIFICATION OF ELECTRICAL WIRING

CABLE	INSTRUMENT CONSOLE	SIMULATOR	FUNCTION
1	Speed control pot	Motor controller GPD 402	Speed control for oil pump drive motor
2	On/off; CPU bypass; Ext. fault/reset; indicator light	Motor controller GPD 502	Power to drive head motor
3	Speed control pot	Motor controller GPD 502	Speed control for drive head motor
4	On/off; CUP bypass; Ext. fault/reset; indicator light	Motor controller GPD 402	Power to oil pump drive motor
5	Hot spot controller	Solid state relay	Temperature control for heating element
6A 6B	#1 BRG controller #2 BRG controller	Solid state relay	Temperature control for heating elements
7	Sump heater controller	Solid state relay	Temperature control for heating elements
8	On/off; precipitator	High voltage power supply	On/off switch for HV power supply
9	Flow measuring switches Man/CPU	Air solenoids	To open/close air valve under the flow measuring reservoir
10	Indicator light	Motor controller GPD 502	Alerts operator that drive head motor has shut down
11	Indicator light	Motor controller GPD 402	Alerts operator that oil pump motor has shut down
12	Hot, Neu, GRD	Circuit breaker on rear panel of simulator frame	110 vac to terminal blocks on console panel (TB1 & TB2)
13	Hot	Circuit breaker on rear panel of simulator frame	110 vac to power strip inside the console (TB2)
14	Hot	Extra, not used	Extra not used

APPENDIX B
SAMPLE OUTPUT FROM DATA REDUCTION SOFTWARE

WRIGHT LABORATORY MINISIMULATOR
DATA SUMMARY FOR 16-HOUR SEGMENT NUMBER 2

Data Type	Minimum	Maximum	Mean	Std. Dev.
Fwd Oil Jet #1	313.4	347.7	335.9	7.3
Fwd Oil Jet #2	337.9	349.9	343.5	2.7
Rear Oil Jet #1	331.1	348.9	340.6	4.7
Rear Oil Jet #2	335.0	344.5	339.4	2.3
Fwd Bearing #1	428.4	512.6	487.5	13.7
Fwd Bearing #2	429.4	492.2	478.7	10.9
Rear Bearing #1	434.5	512.3	497.5	13.4
Rear Bearing #2	428.9	499.4	477.1	9.5
Hot Spot #1 (split connection)	424.4	480.1	472.0	12.2
Head	466.4	579.2	569.9	22.1
Sump	339.7	356.1	349.6	1.4
Hot Spot (direct connection)	420.9	480.3	471.4	12.7
Speed	-1.3	9965.7	9768.6	1117.4
Torque	0.0	0.4	0.3	0.0
Flow Rate	100.0	100.0	100.0	0.0
Pressure - Oil before Filter	0.0	10.5	2.2	2.4
Pressure - Oil After Filter	0.0	9.8	2.0	2.3

APPENDIX C

SAMPLE TEST REPORT

TEST RESULTS

ON

Lubricant MIL-L-7808, Code 0-087-2B

TEST NO. 4
Completed May 13, 1991

MINISIMULATOR TEST NUMBER 4

Test Temperatures

Location	Temperature, Degrees F	
	Target	Test Avg.
No. 1 Bearing		
Top	500	487.5
Bottom	500	478.7
No. 2 Bearing		
Top	500	497.5
Bottom	500	477.1
No. 1 Brg. Oil In		
Top	340	335.9
Bottom	340	343.5
No. 2 Brg. Oil In		
Top	340	340.6
Bottom	340	339.4
Bearing Housing	570	569.9
Hot Spot		
Top		472
Bottom		471.4
Test-Oil Sump	350	349.6

Test Parameters

Item	Target	Test Average
Test-Oil Flow, cm^3/min	0	0
Shaft Speed, rpm	0	0
Bearing Torque, lb-in	0	0

48-HOUR MINISIMULATOR TEST SUMMARY DATA

Test No. 4
Lubricant MIL-L-7808, CODE: 0-087-2B

DEPOSIT DEMERITS

ITEM	RATING	FACTOR	DEMERITS
No. 1 End cover	11	1	11
No. 2 End Cover	10	1	10
Housing ID	179.5	2	359
Hot Spot	12.5	3	37.5
Drive Shaft	45	2	90
Bearing Retainer	9	2	18
Slinger	0	1	0
Spacer	0	1	0
No. 1 Bearing Mount	33	3	99
No. 2 Bearing Mount	38.5	3	115.5
No. 1 Bearing	15.63	5	78.15
No. 2 Bearing	25.3	5	126.5
TOTAL			944.65
Overall Rating	78.7		
Not included in rating:Sump - wall	100% clean		
bottom	100% clean		
Oil consumption, cm^3/hr	3		
Accumulated filter wt, g	0.0712		
Sump temperature, (farenheit)	350		
Bearing temperature	500		
Hot spot temperature	unheated		
Test duration, hr	48		

MINISIMULATOR TEST NUMBER 4

Lubricant Performance Summary

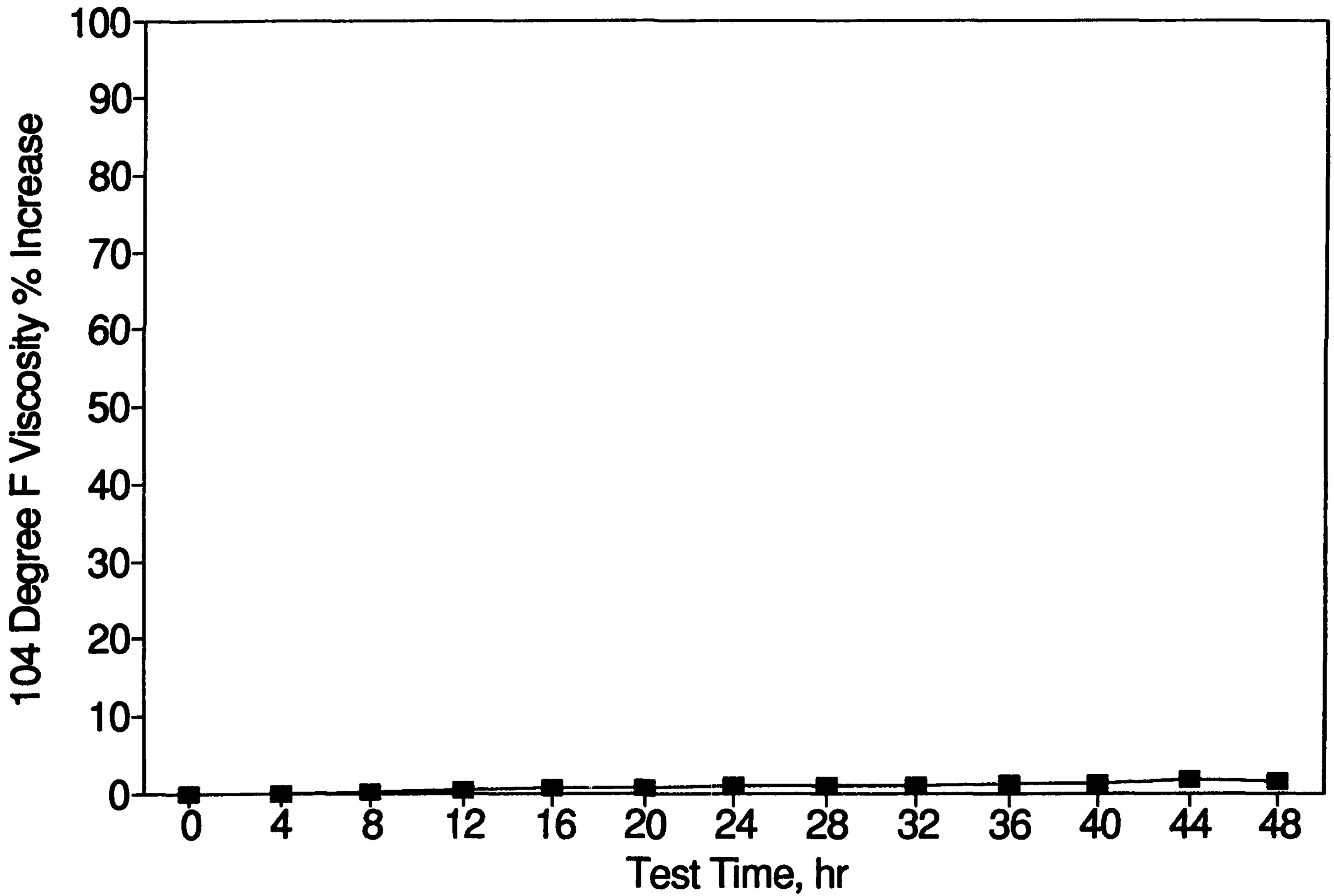
Test Time, hr	Viscosity, @ 104°F (40°C) Centistokes	% Increase	Neut. No., mg KOH/g
0	12.33	-	0.01
4	12.32	-0.1	0.07
8	12.72	0.39	0.24
12	12.85	0.52	0.53
16	13	0.67	0.95
20	13	0.67	1.04
24	13.18	0.85	1.64
28	13.33	1	2.27
32	13.49	1.16	2.61
36	13.61	1.28	2.9
40	13.65	1.32	3.23
44	13.94	1.61	3.64
48	13.9	1.57	3.86

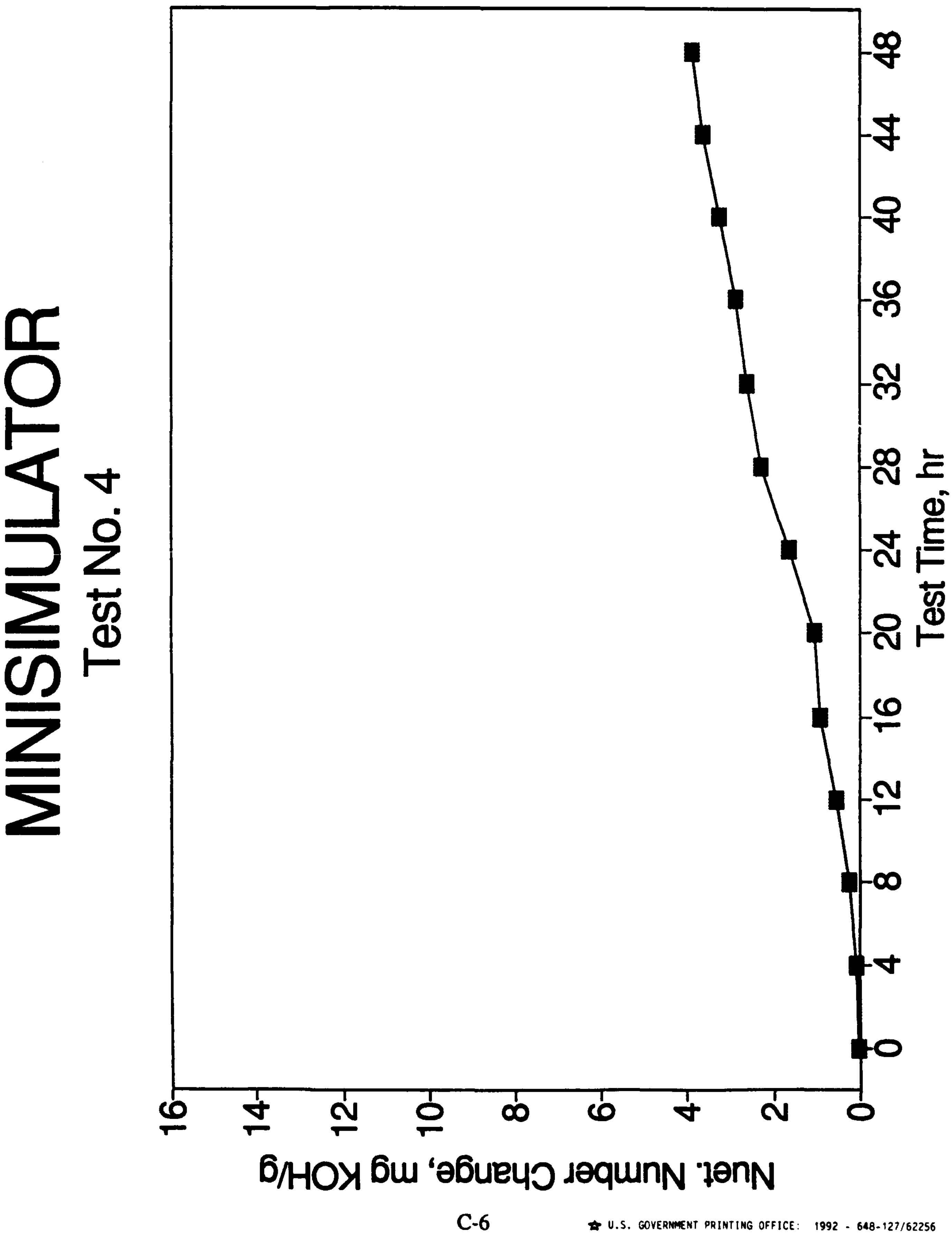
Metal Corrosion

Metal	Wt Change, mg/cm^2
Al	-0.02
Ag	-0.06
Bz	
Fe	-0.04
M-50	-0.02
Mg	.
Ti	-0.02
WSP	0

MINISIMULATOR

Test No. 4





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